

# *Miniaturized aerosol, cloud, and radiometric instruments for light weight autonomous UAVs*

G. Roberts, C. Corrigan, M.V. Ramana, V. Ramanathan

Center for Atmospheric Sciences  
Scripps Institution of Oceanography  
University of California, San Diego  
La Jolla, CA



2006 NASA Earth Science Technology Conference

# The Maldives Autonomous Unmanned Aerial Vehicle Campaign (MAC)

06 March - 01 April, 2006

## Science Team: Scripps Institution of Oceanography

**V. Ramanathan** (*PI*)

**H. Nguyen** (*Mission Director*)

**C. Corrigan** (*Aerosols*)

**M.V. Ramana** (*Radiation*)

**G. Roberts** (*Lead Instrument Scientist*)

## Flight Team: Advanced Ceramic Research

**A. Mulligan** (*Project Director*)

**M. Patterson** (*Project Manager*)

**L. Wardell** (*Project Leader*)

**P. Corcoran** (*Pilot-in-Command*)

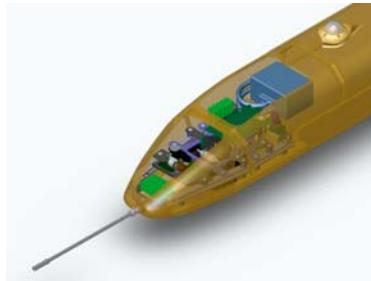
**E. Hooper** (*Pilot*)

**R .A.G. Pineda** (*Pilot*)

# Outline

---

- Miniaturized instrument payload & development
- Instrument performance & validation
- Case study & preliminary results – Maldives AUAV Campaign



# UAV instrument deployment

2003 – 2004

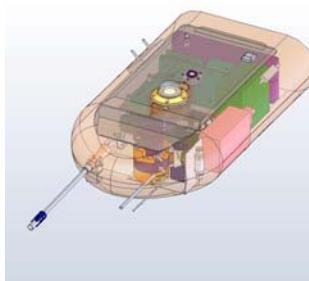


Initial development <i>Jan. – May '03</i>	Seattle, WA <i>Sept. '03</i>	El Mirage, CA <i>Dec. '03</i>	Seattle, WA <i>July '04</i>	El Mirage, CA <i>Sept. '04</i>	MALDIVES <i>Oct. '04</i>
--	---------------------------------	----------------------------------	--------------------------------	-----------------------------------	-----------------------------

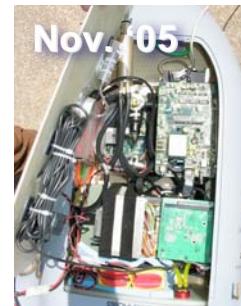
2005 – 2006

Tucson, AZ <i>May '05</i>	Tucson, AZ <i>July '05</i>	Yuma, AZ <i>Aug. '05</i>	El Centro, CA <i>Nov. '05</i>	MALDIVES (MAC) <i>Mar. '06</i>
------------------------------	-------------------------------	-----------------------------	----------------------------------	--------------------------------------

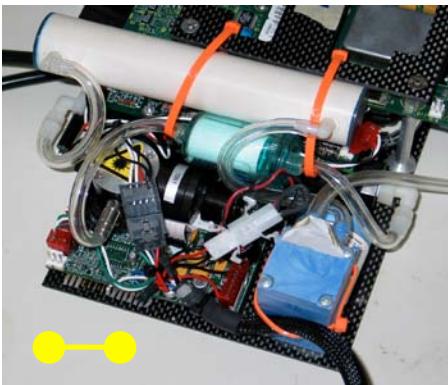
Thanks Milt



Test Flights  
Instrumented Flights  
Experiments



# UAV instruments



**Optical Particle Counter (580 g)**  
 $\rightarrow N_{OPC}$ ;  $0.3 < D_p < 3 \mu\text{m}$

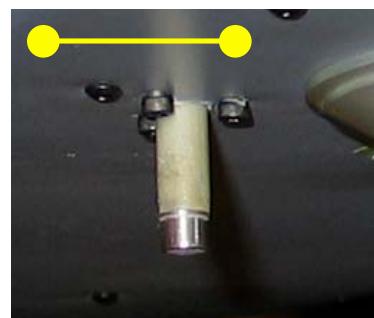


**Aethalometer (820 g)**  
 $\rightarrow$  absorbing aerosol



**Pyranometer (190 g)**  
 $\rightarrow$  irradiance  $0.3 - 2.8 \mu\text{m}$

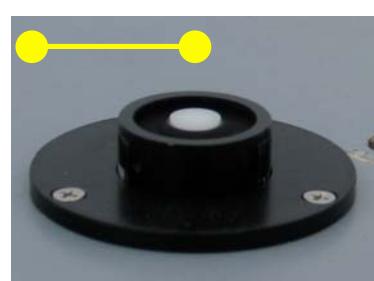
[=] 1 inch



**T/RH probe (50 g)**  
 $\rightarrow$  Temperature & RH



**Aerosol inlet & splitter (150 g)**  
 $\rightarrow$  unbiased aerosol sampling



**PAR radiometer (45 g)**  
 $\rightarrow$  irradiance  $400 - 700 \text{ nm}$



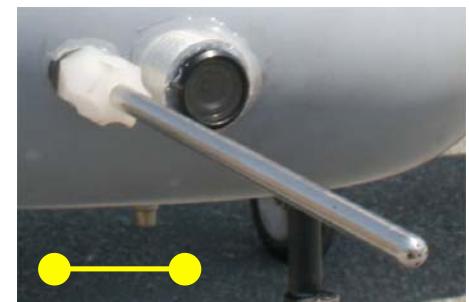
**LWC probe (450 g)**  
 $\rightarrow$  Cloud water ( $\text{g m}^{-3}$ )



**Condensation Particle Counter (870 g)**  $\rightarrow N_{CN}$ ;  $D_p > 10 \text{ nm}$



**Cloud Droplet Spectrometer (1.4 kg)**  $\rightarrow$  distr.  $1 < D < 50 \mu\text{m}$

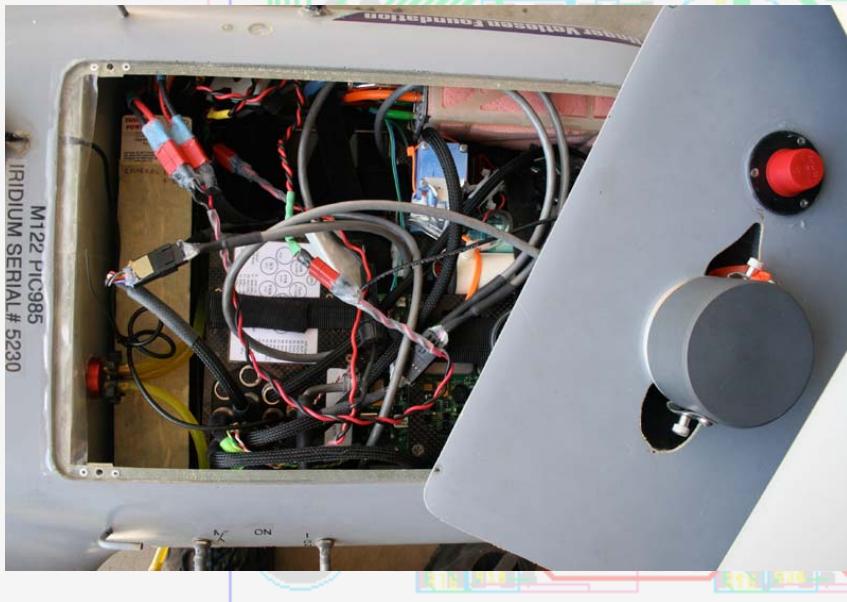


**Gust probe (400 g) & video camera (280 g)**  
 $\rightarrow$  turbulence & cloud targeting

# Power & data system

## Data acquisition system

- C-programmable single-chip computer
- CompactFlash storage
- 16 channels of 16-bit A/D
- 6 channels serial communication
- expansion of A/D and serial channels

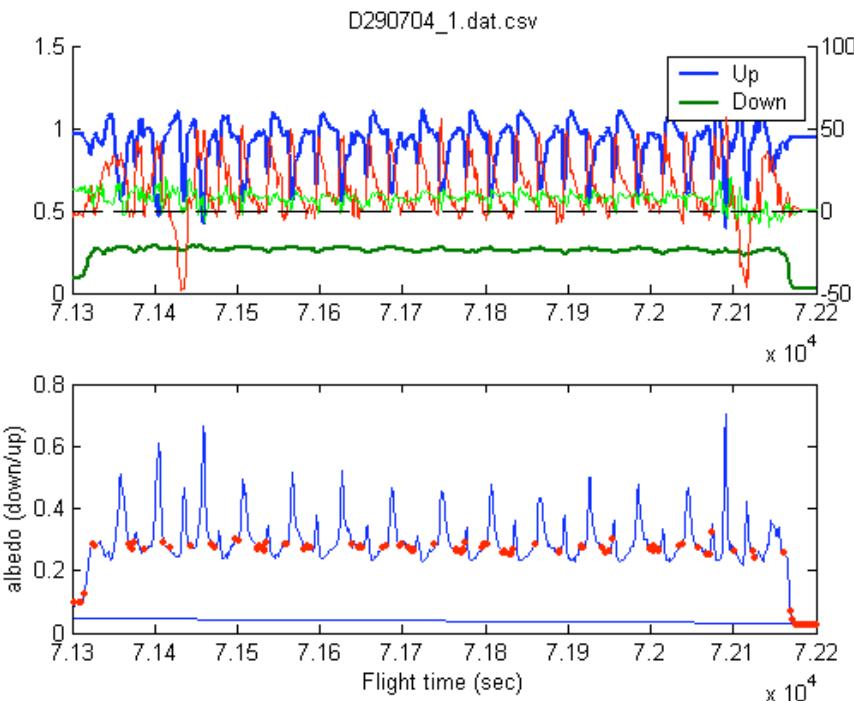


## Interface board

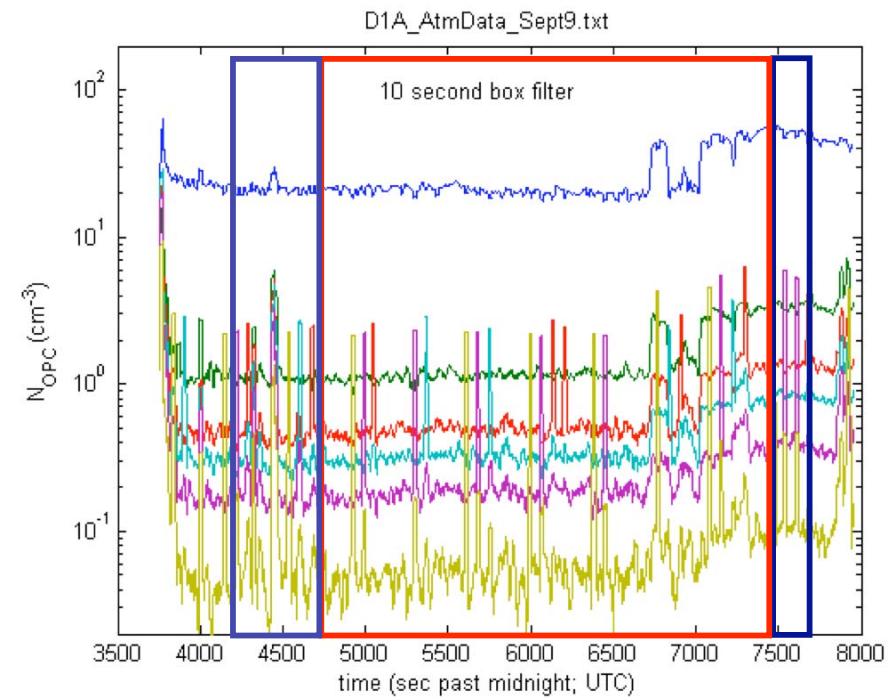
- power / data in same connector
- accommodates new instruments easily
- GPS for timing and spatial coordination
- solid-state relays to turn on/off devices
- miniature pressure sensors
- onboard circuits for temperature measurements
- PC104 power supply ( $\pm 5$ ,  $\pm 12$  VDC)



# 1<sup>st</sup> SIO UAV radiometric & aerosol measurements



Seattle, WA July '04

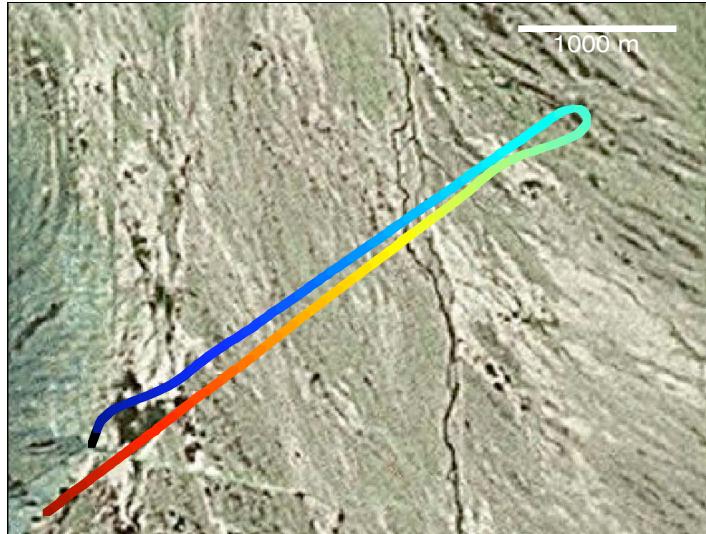


El Mirage, CA Sept. '04

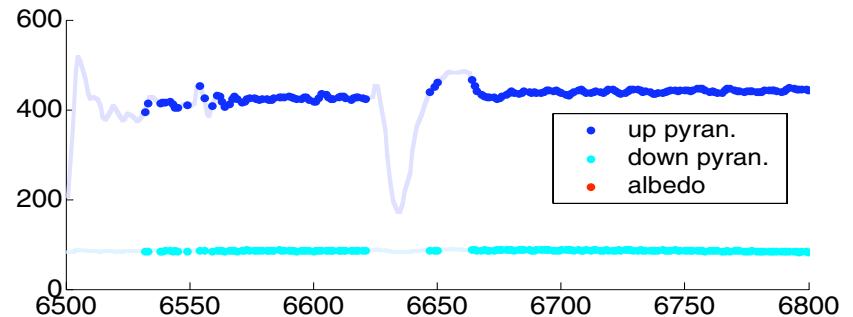
- pyranometer measurements
- albedo during level portions (red dots)

- aerosol concentrations: 0.3, 0.5, 0.7, 1.0, 2.0, 3.0  $\mu\text{m}$   $D_p$
- red box → autonomous flight

# Autonomous straight & level flights



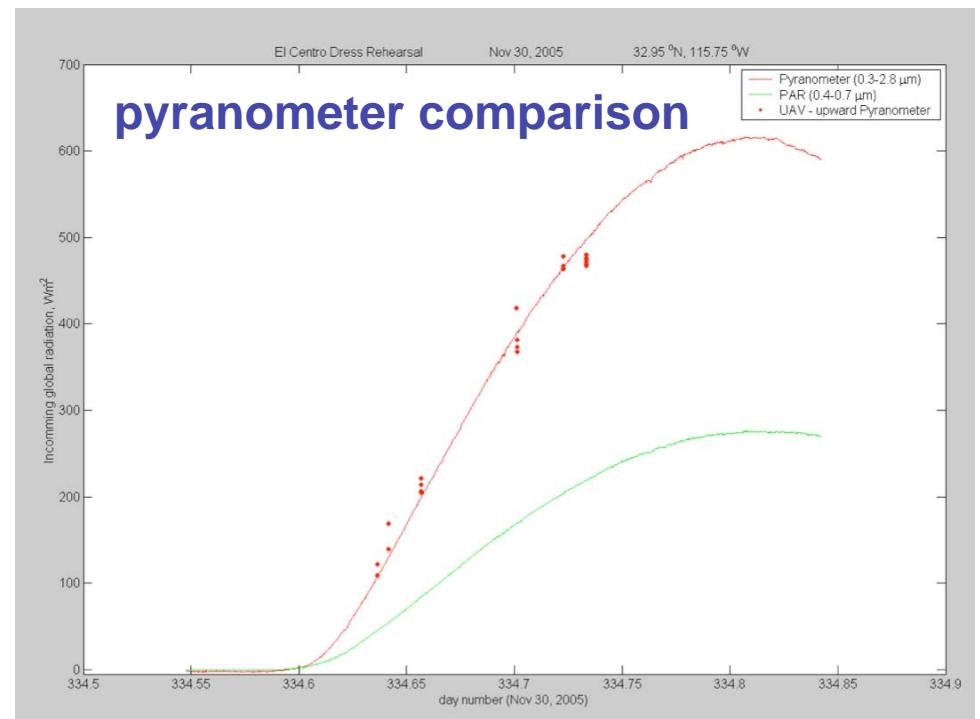
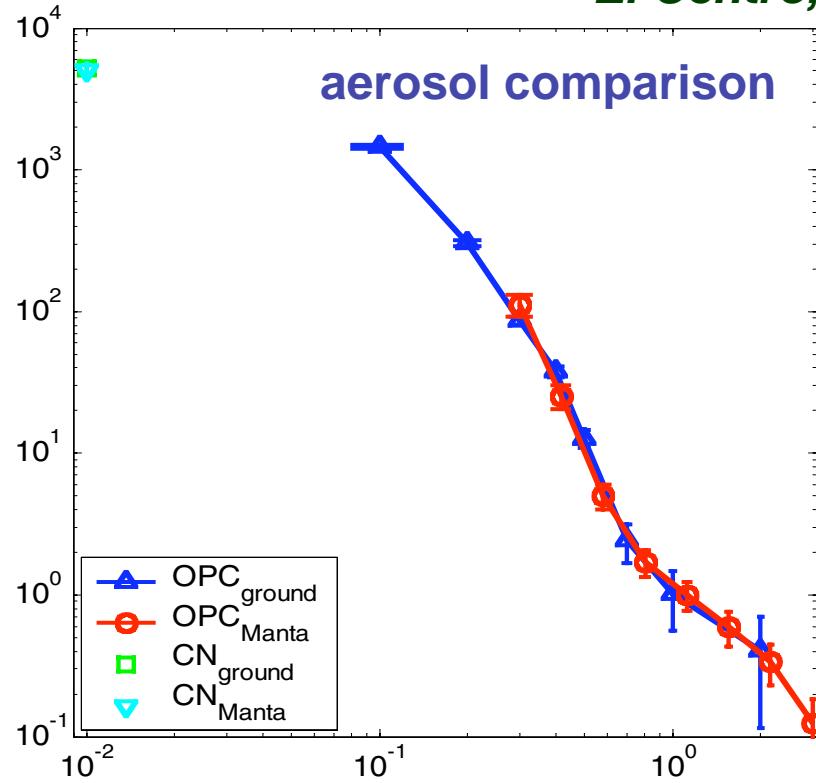
Map overlay and time series of flight track on 15 August 2005 (Yuma, AZ).



Time series of up & down pyranometer measurements and aircraft pitch/roll.

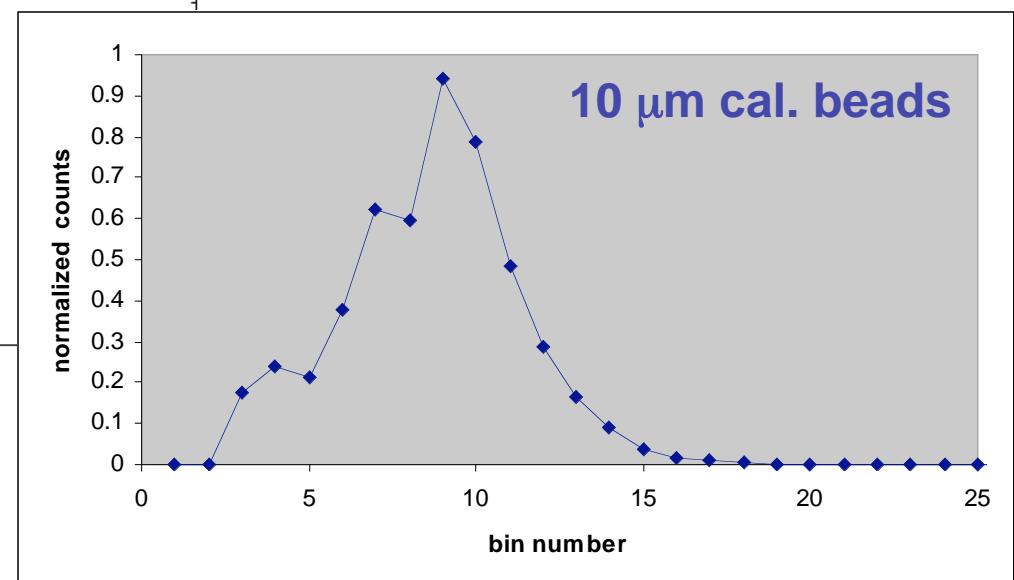
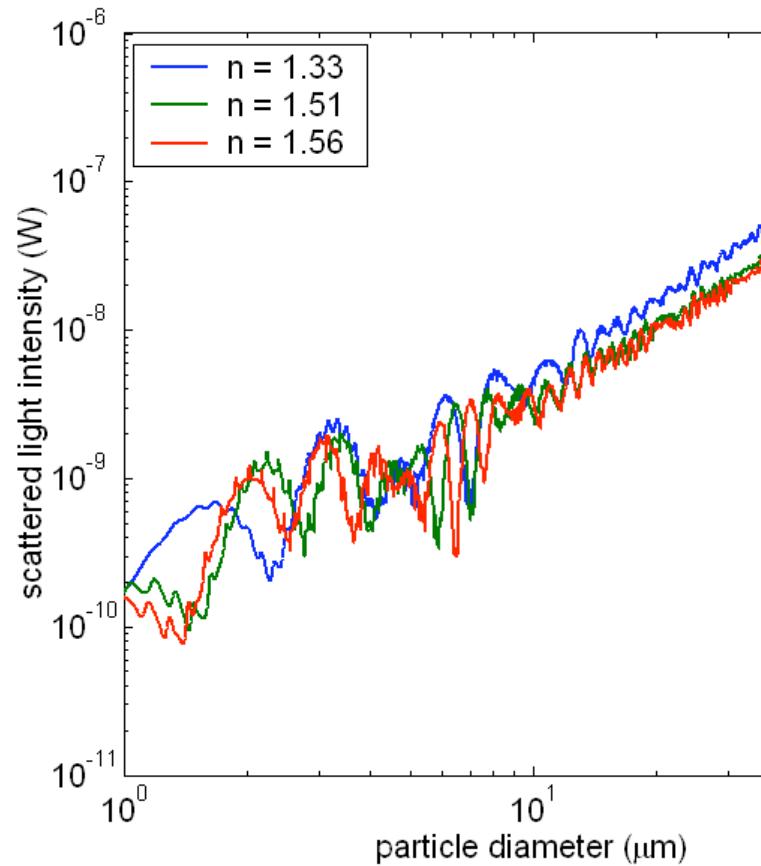
# Pre-MAC instrument validation

*El Centro, CA; Nov. '05*



- Aerosol and radiometric measurements  
→ good agreement with ground based observations
- Performance validation of CPC, OPC, aerosol inlet, pyranometers & PAR sensors

# Cloud Droplet Probe calibrations



- Standard calibration with 3 to 20  $\mu\text{m}$  glass spheres
- UAV airspeed  $\rightarrow$  droplet conc.

# Maldives UAV Campaign (MAC)

## *Technology demonstration:*

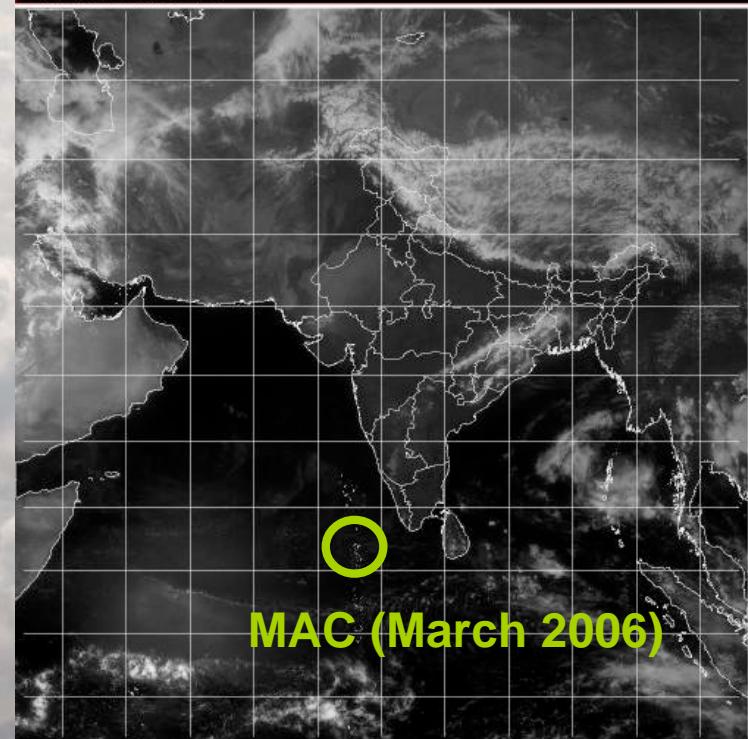
- 3-AUAV stacked flights

## *Science:*

- Vertical profiles of aerosols, clouds and radiation fluxes
- Direct measurement of solar absorption & black carbon
- Linking aerosols with cloud microphysical properties and cloudy sky albedo

INSAT satellite image of Indian Ocean at 0900Z 28 March 2006

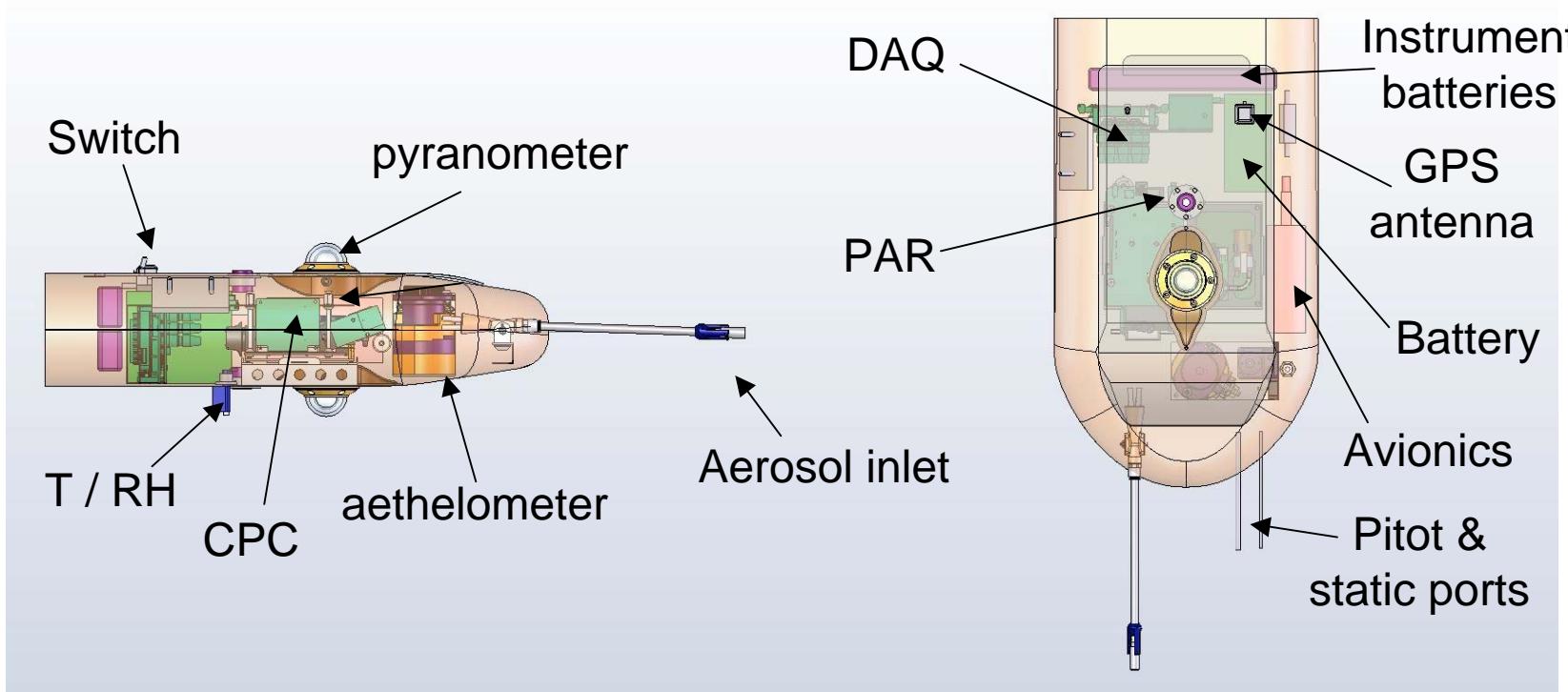
VIS No Enhancement



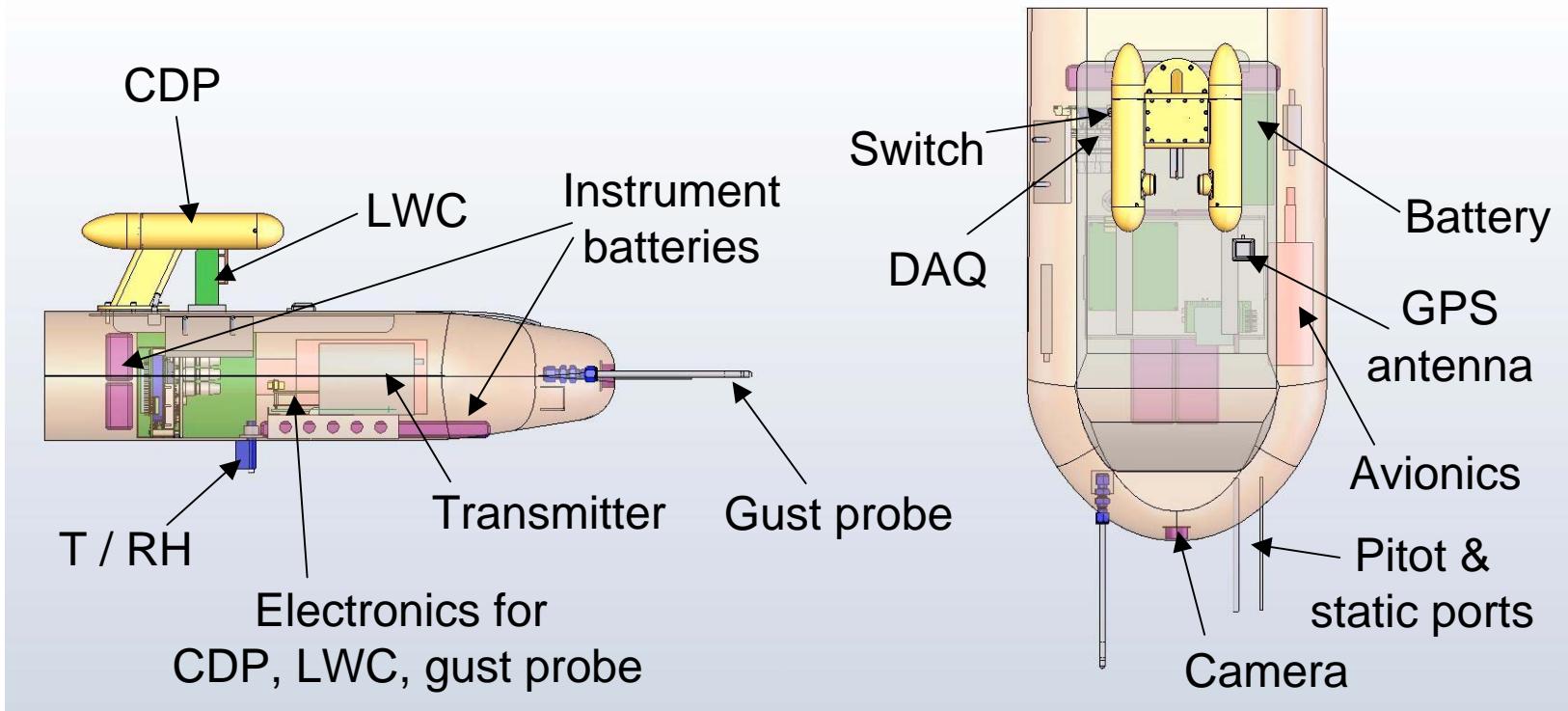
# MAC UAV payloads

<i>Payload for each platform</i>	<i>Power (W)</i>	<i>Weight (kg)</i>	<i>Instrumentation</i> <small>(batteries not included)</small>
<b>Above-cloud</b> → aerosol, absorption & radiometric	27	3.6	Optical Particle Counter Condensation Particle Counter Aethalometer Absorption Photometer Pyranometer (▼▲) PAR (▼▲)
<b>In-cloud</b> → cloud physics	27	3.0	Data acquisition & T / RH / P Cloud Droplet Probe Liquid Water Content Probe Gust Probe Digital Video Camera Data acquisition & T / RH / P
<b>Below-cloud</b> → aerosol & radiometric	20	2.8	Optical Particle Counter Condensation Particle Counter Pyranometer (▼▲) PAR (▼▲) Data acquisition & T / RH / P

# Above/below cloud platform



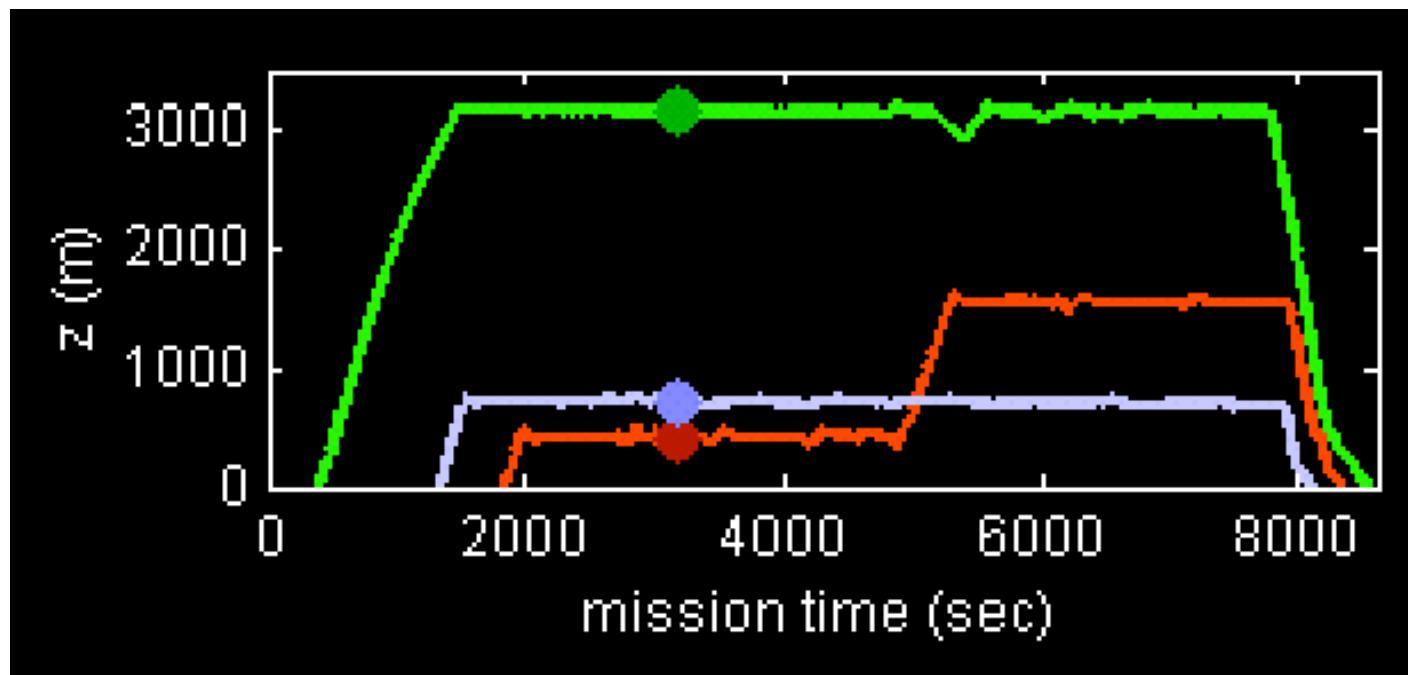
# In-cloud platform



# Case study – MAC-F11

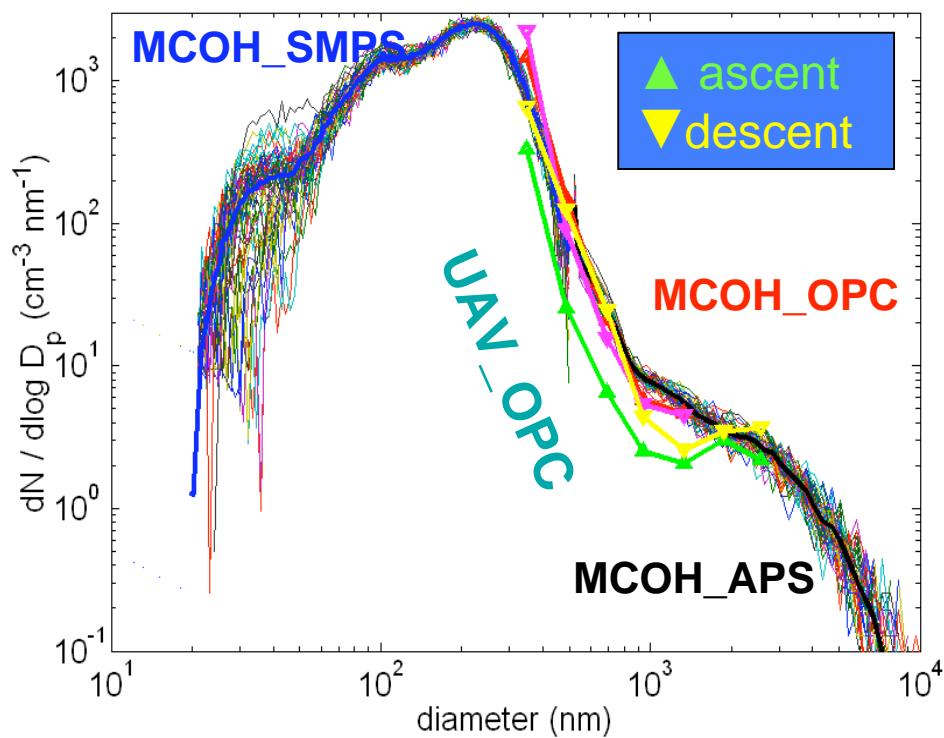
## 23 March 2006

- Stacked flights during elevated dust & pollution period
- Show instrument performances

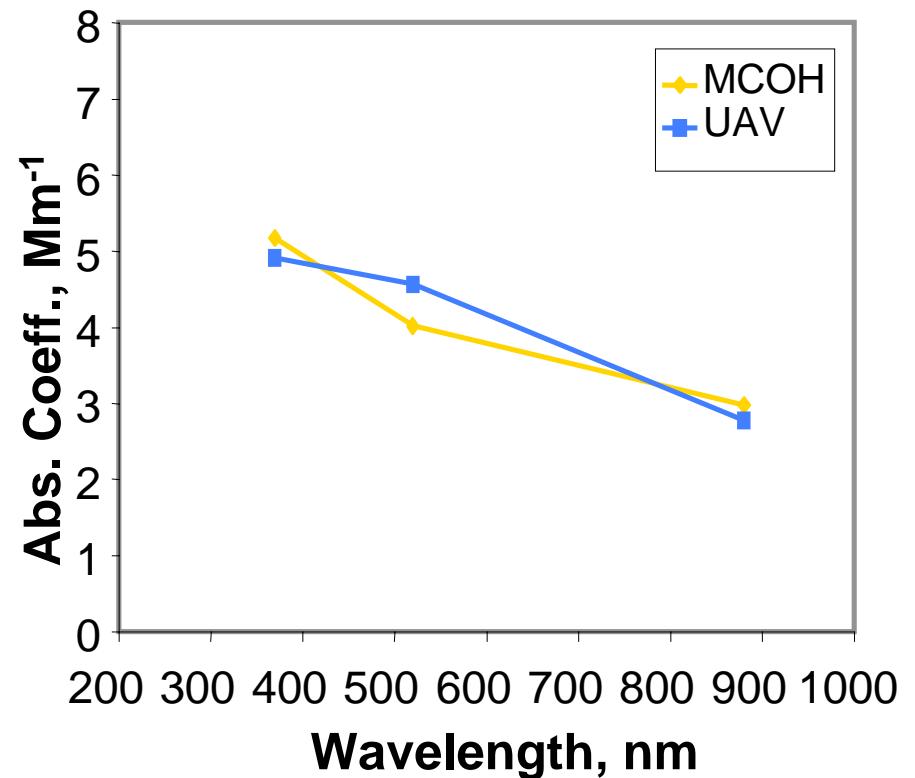


# MCOH-UAV aerosol comparisons

*Aerosol size distribution*



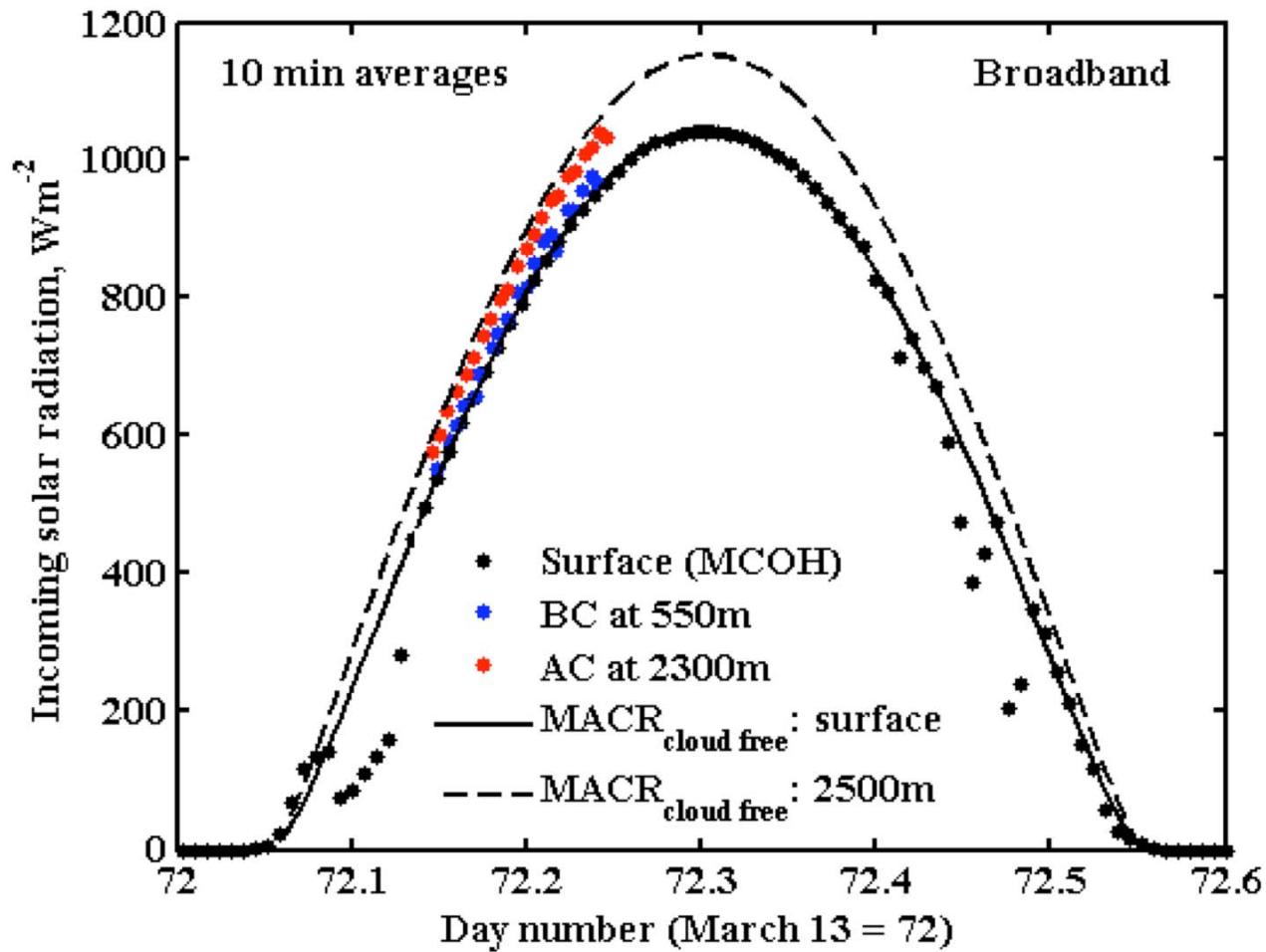
*Aethelometer absorption*



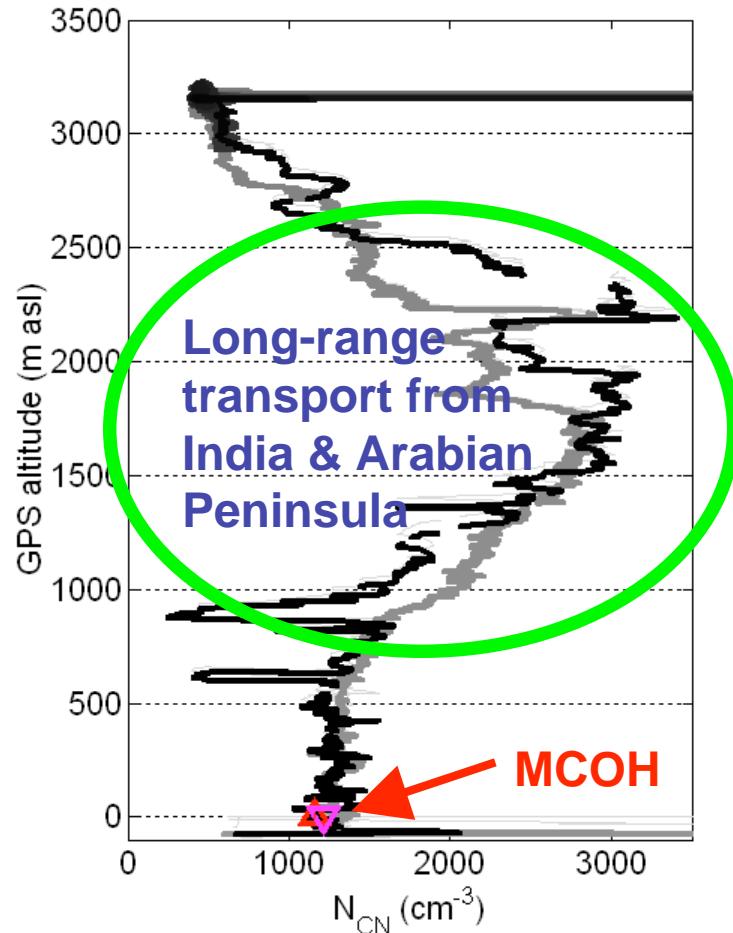
→ Good agreement between boundary layer UAV and ground-based aerosol observations

Averages during MAC-F11 vertical profiles

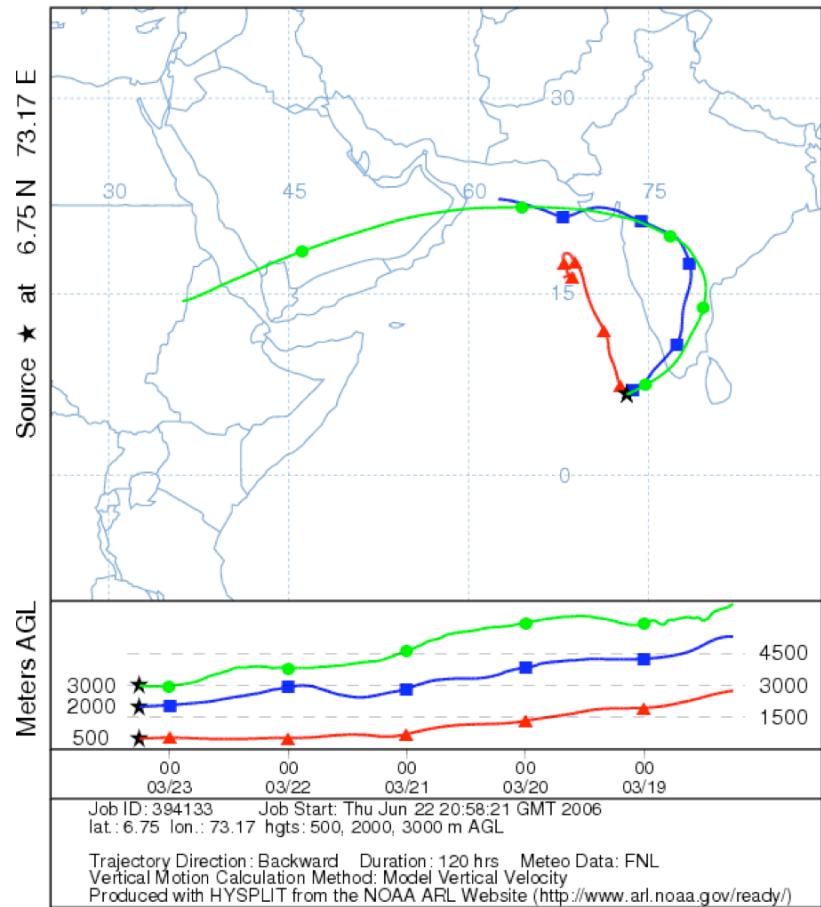
# Radiometric measurements



# Aerosol vertical profiles



NOAA HYSPLIT MODEL  
Backward trajectories ending at 06 UTC 23 Mar 06  
FNL Meteorological Data



- elevated aerosol concentrations above the boundary layer
- need for continuous *in situ* measurements aloft

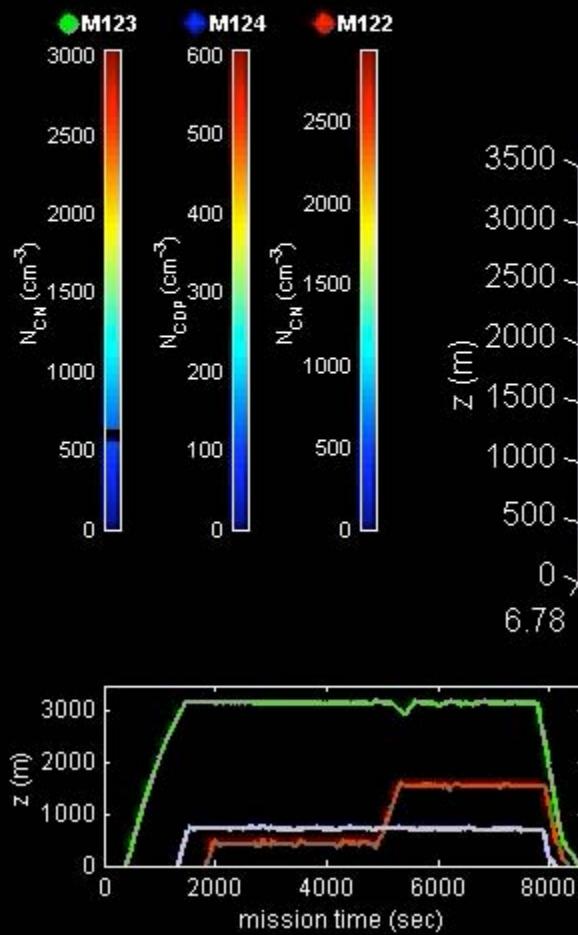
# Cloud pass



**30 sec snapshot of trade cumulus  
→ ~30 m resolution of clouds**

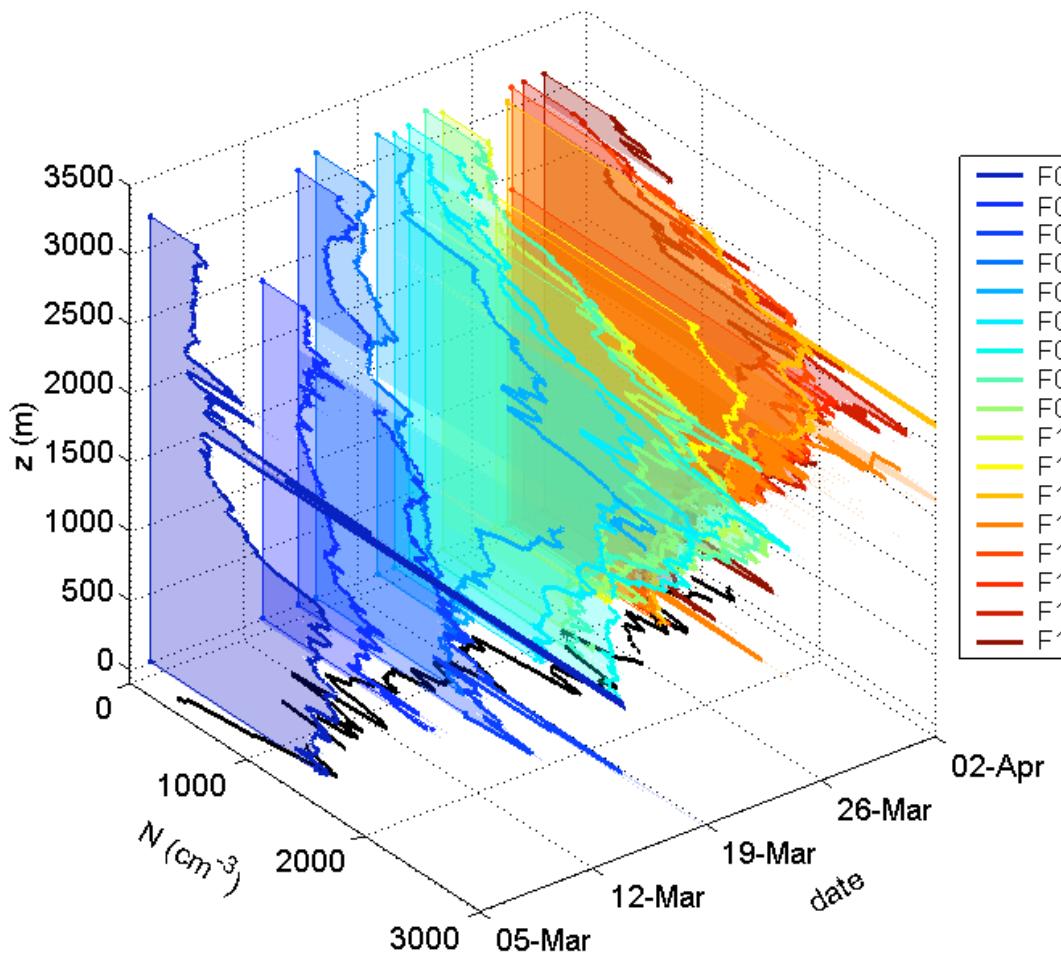
# MAC Flight 11

23-Mar-2006 03:40:53Z



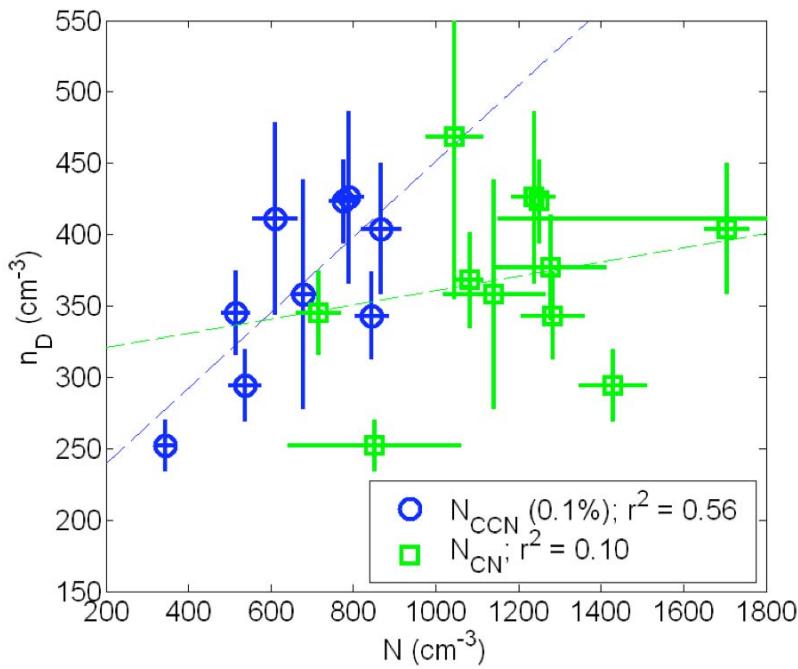
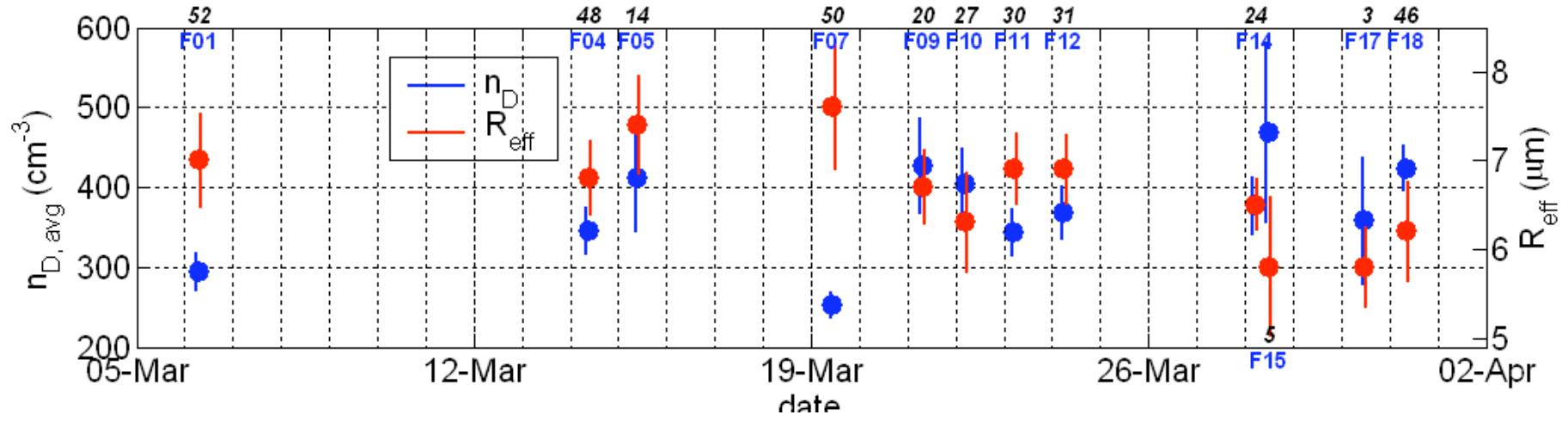
© G. Roberts

# MAC aerosol profiles



- Profiles to 3000 m asl
- Aerosol layers increased in altitude throughout the experiment → transition from below to above marine boundary layer
- Peak  $N_{\text{CN}}$  ca.  $3000 \text{ cm}^{-3}$

# MAC cloud properties



- ~350 cloud events
- effective radius decreases during experiment
- effective radius & cloud droplet number inversely correlated
- $N_{\text{CCN}}$  &  $n_D$  correlation

# Development of streamwise CCN

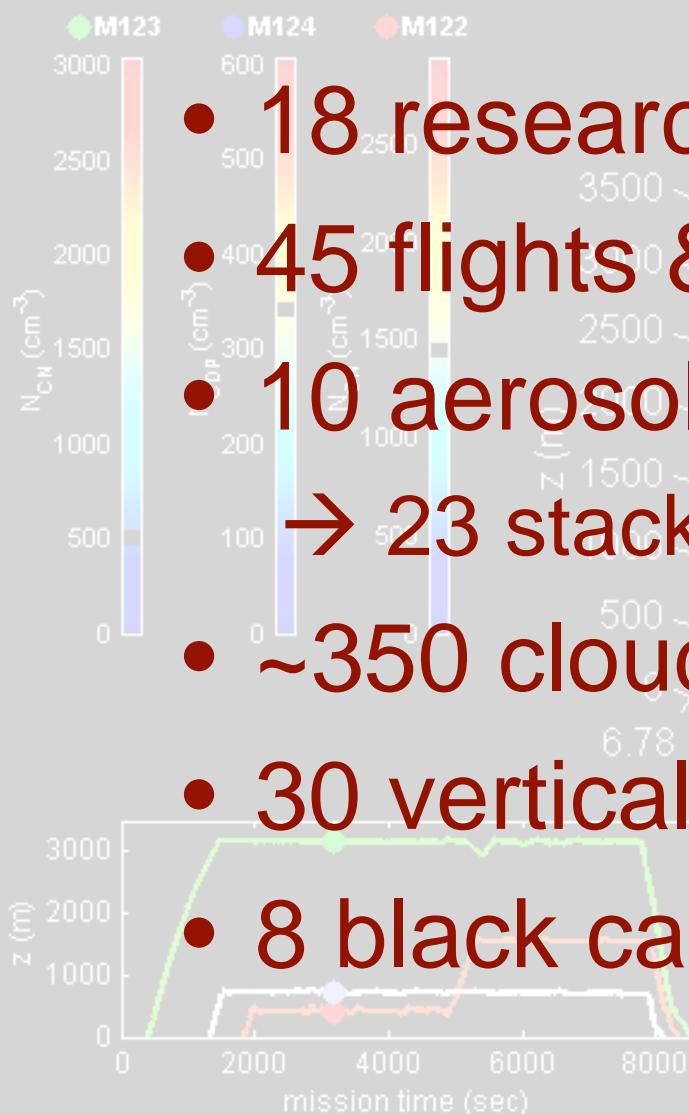


Funded by NSF & NOAA

23-Mar-2006 04:34:08Z

MAC Flight 11

# MAC Flight Summary



# UAV instrument summary

---

- Radiometric, aerosol, cloud physics instrumentation
- Payloads (< 4 kg) selected for scientific missions
- Flexible data acquisition system
  - 16 channels A/D & 6 serial
  - Integrated GPS, pressure, temperature, RH, SSR control
- AUAV instruments validated & perform well
- Straight-level platform improves radiometric observations
- Simultaneous observations of earth's atmosphere
- Maldives AUAV campaign → 18 research flights w/ 120 hours

# Acknowledgements

NSF/ NOAA/NASA/Vetlesen/Alderson  
Maldives Govt

Fahey/Fein/Koblinsky/Kuettner/Maring/Yuhas  
NASA-Dryden (Curry/Jennison)

ACR Team: Patterson/Mulligan/ Maldives Crew

